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20021009 024

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

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1. REPORT DATE *(DD-MM-YYYY)*
11-06-2002

2. REPORT TYPE
Journal Article - refereed

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Environmental Data Collection From The AQS-20

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
0603704N

6. AUTHOR(S)
Michael M. Harris, William E. Avera, Leonard D. Bibee, J. M. Null

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER
74-7441-A2

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval Research Laboratory
Marine Geosciences Division
Stennis Space Center, MS
39529-5004

8. PERFORMING ORGANIZATION REPORT NUMBER

NRL/JA/7440—02-1009

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
SPAWAR PMW 155
4301 Pacific Highway
San Diego, CA 92110

10. SPONSOR/MONITOR'S ACRONYM(S)
SPAWAR

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release, distribution is unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
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15. SUBJECT TERMS
environment data, Mine Hunting Sonar, Remote Mine Hunting System

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
Unclassified	Unclassified	Unclassified	Unlimited	12	Michael M. Harris
					19b. TELEPHONE NUMBER *(include area code)* 228-688-4420

Environmental Data Collection from the AQS-20

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Abstract

The Naval Research Laboratory (NRL) under the technical direction of SPAWAR PMW-155 and the sponsorship of the Oceanographer of the Navy, N096, examined the technical feasibility of extracting environmental data from the AQS-20 Mine Hunting Sonar towed from both the MH-60 helicopter and the AN/WLD-1 Remote Mine Hunting System. Multibeam bathymetry and sediment information can be extracted from the AQS-20 and used in near real-time in tactical decision aids like the Mine Warfare Environmental Decision Aids Library (MEDAL). These conclusions are based on AQS-20 experiments conducted in June 1998, July 1999 and June 2001. This paper discusses the advantages of near real-time environmental data in MCM and describes a proposed Environmental Data Collection (EDC) Mode of operation for the AQS-20.

Introduction

The Naval Research Laboratory (NRL), Naval Oceanographic Office (NAVOCEANO) and the Naval Surface Warfare Center, Costal Systems Station are collaborating to extract environmental data from the AQS-20 mine hunting sonar. Technical feasibility was demonstrated using a "Through the Sensors" (TTS) approach. This efficient dual use of tactical sensor data provides normal MCM tactical data plus environmental data that can be used same day by the host platform, near real-time by regional centers and long-term by NAVOCEANO.

TTS data is needed to assemble the environmental picture. Environmental support for mine warfare operations includes supplementing historical data sets with measurements in theatre. These real-time measurements are used to verify historical information, fill in gaps, replace perishable data, and provide new information.

The AN/AQS-20 is a variable depth, mine hunting sonar system designed to detect, classify and identify moored and bottom mines using side-scan, forward-looking, and Volume Search Sonar (VSS) systems from deep to very shallow water.[1] The system is designed to be towed from either the MH-60 helicopter or the AN/WLD-1(V) remote minehunting system.

Environmental data can be extracted from the AQS-20 data through additional processing. The AQS-20 provides both a low-resolution *mission data* stream and a *high-resolution data* stream. *Mission data* is 2-bit intensity information with 1.4-yard range resolution. *High-resolution data* contains 16-bit beam intensity information at .1-yard range resolution.

The AQS-20 has several modes of operation[2] each using different sensor combinations. In the *Single Pass Shallow* (SPS) Mode the Side Look Sonar (SLS) Data provides side-scan information to image the seafloor along a varying path that is a constant altitude above the seafloor. Single beam bathymetry can be extracted in this mode using altitude information from the Acoustic Doppler sonar. In the *Volume Mode*

of operation the VSS sweeps a fan shaped area searching for moored mine shapes in the water volume while flying at a constant depth below the sea surface. VSS beam information can be processed to pick out bottom detections that equate to multibeam bathymetry, and the nadir beam can be processed for determination of sediment type. In the proposed *Environmental Data Collection* (EDC) Mode the AQS-20 will interleave SLS and VSS pings using a single beam former on the tow body. The EDC mode is the only mode that provides for collection of side-scan imagery, multibeam bathymetry and sediment profile data during the same flight.

Environmental Dependence of MCM

Due to the temporal and spatial variability of vast littoral regions, accurate real-time environmental information assimilated with available historical data is required to adequately characterize the MIW littoral battle space. Demonstrated repeatedly in numerous Mine Counter Measures (MCM) exercises, near real-time characterization of the seafloor can significantly impact the MCM Commander's decisions allowing him to bypass geographically challenging areas, alter routes, breach an area and achieve MCM goals in less time.

Current MCM doctrine uses a measure of bottom composition, estimated percent mine case burial, bottom roughness and bottom clutter density to determine the bottom category for a given location. Doctrine provides a listing of probability of detection values associated with each of these bottom category descriptions. The probability of detection values along with sonar detection widths derived from sound velocity profiles determines the MCM track spacing to achieve the required clearance level. The AQS-20 sensor suite is capable of measuring all of the necessary environmental data types needed to determine bottom category value.

Where Does Environmental Data Come From Now

NAVOCEANO collects and maintains geologic, bathymetric and oceanographic databases in support of Fleet Mine warfare requirements. Under the MIW Campaign Plan initiated by the Chief of Naval Operations, Expeditionary Warfare Branch, NAVOCEANO is tasked with developing and maintaining high-resolution digital bottom-mapping (side scan imagery) databases and environmental databases to support MCM forces. These data bases include bathymetry, sediments, bottom roughness, clutter density, sound velocity, currents, visibility, and a master contact databases. Currently, these data are formatted for ingest into the Mine Warfare Environmental Decisions Aid Library (MEDAL) and also for ingest into the Comprehensive Environmental Assessment System (CEAS).

NAVOCEANO also provides in theater support via a Bottom Mapping Team that processes AN/AQS-14 side scan data for clutter density and bottom roughness determination. EOD diver arm thrust reports provide point sediment information.

Historical Data Limitations

Mission effectiveness can be severely degraded by less than optimum environmental conditions. Due to limited survey ship coverage in remote regions, bottom roughness and NOMBO density are often difficult quantities to assess since they typically require high resolution bathymetric and sidescan sonar surveys which are not always

readily available. Data perishability is also an issue in shallow water littoral regions where environmental parameters often have relatively short temporal and spatial scales and require continuous monitoring.

During the Marcot/Unified Spirit '99 Exercise held in St. John's Bay New Foundland, historical environmental sediment databases were provided to MCM Forces prior to the start of the exercise. These databases were based on a compilation of hydrographic surveys previously conducted by the Canadian Hydrograhic Office. Based on the historical information provided, MIW bottom types were assigned and mine hunting tracks and clearance time lines were calculated. The left hand side of Figure 1 shows the assumed bottom types for the Marcot Oparea based on *a-priori* historical information. However, analyses of AN/AQS-14 side scan sonar data collected during reconnaissance AMCM missions suggested that the bottom types were more benign than initially assumed. The right hand side of Figure 1 illustrates the derived bottom types from these AMCM missions. As evident from this figure, prior to the exercise it was assumed that much of the operations area was a more challenging "B2" environment. However, analysis of the side scan imagery collected from the AQS-14 revealed that the majority the bottom was flat and featureless "A1" type bottom. The probability of detection for an "A1" type bottom is generally higher than that of a more "B2" type bottom implying reduced clearance time lines for the same level of clearance. This revised "Through the Sensor" (TTS) characterization of the Marcot Oparea based on the AQS-14 data significantly decreased the overall clearance times and provided the MCM Commander with a "realistic" estimate of percent clearance based on insitu environmental data.

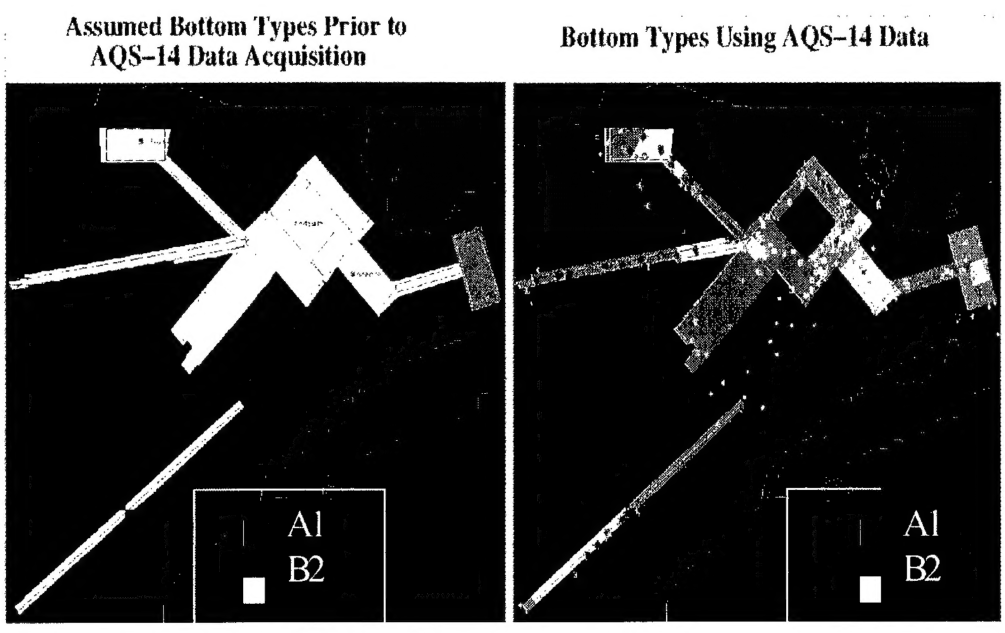


Figure 1

MIW Bottom types for Marcot/Unified Spirit '99 Oparea.

Prior to the Joint Task Force Exercise (JTFEX 02-1) off on Onslow Bay, NC, NAVOCEANO conducted a high resolution side scan sonar survey in the JTFEX oparea. Collected data were analyzed and provinced according to bottom roughness, clutter density, and impact mine burial, and finally MIW bottom type. Figure 2 is the MIW bottom types developed from this high resolution survey. Prior assessments in this area assumed mostly a "B1" environment; however, as evident from Figure 2, there are significant spatial variations in sediment type in this region.. In this example, the bottom type characterization derived through high resolution survey data resulted in an increase in clearance time lines than if an assumed "B1" bottom type was used in the calculations. However, it should be evident that this assumption would of resulted in a "false" sense of mine clearance. The results illustrate the importance for knowing accurate bottom characteristics at the time of an operation.

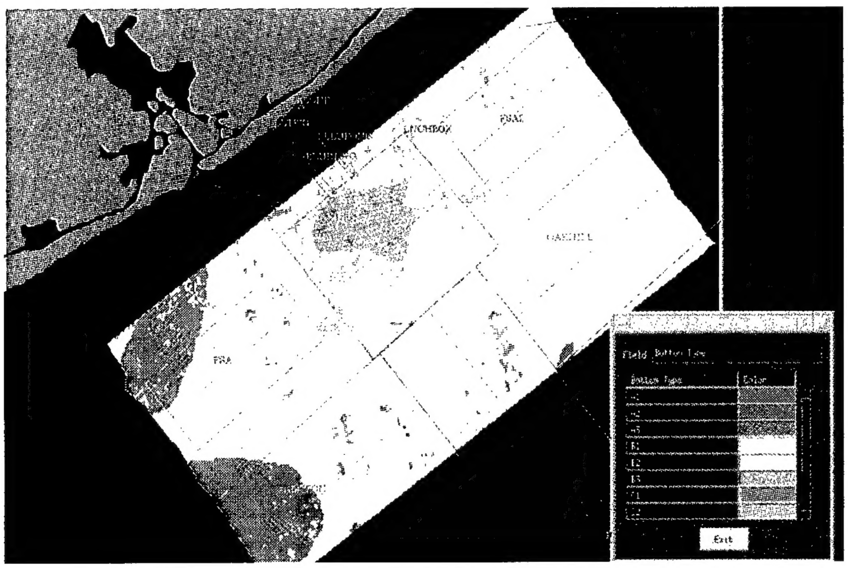


Figure 2

MIW bottom types based on high resolution side scan sonar survey off of Onslow Bay, NC.

In another example, historical sediment data from south of Panama City, FL were compared to grab samples collected in April 2001. Mine burial percentage data matched in approximately 70% of the samples. However it is important to note that even subtle discrepancies between the historical and observed bottom types can be significant in terms of MCM detect to engage timelines. Historical sediment data indicated that the bottom types varied from "B" to "C" type along the track. Using MEDAL to determine a simple clearance based on bottom type, suggested the result of assuming a "B" over "C" can impact the operational timelines by as much as a factor of 60% to 300% depending on clutter category for that region. It can also result in the MCM Commander committing his forces to mine sweeping operations in lieu of mine hunting.

Real-Time In-Situ Environmental Data Collection

Real-time environmental data is critically needed to adequately characterize the temporal and spatial variability in the littoral to ensure MCM mission success. The AQS-20 can provide real-time environmental data in a TTS concept for use in tactical decision aids. The notion is to improve situational awareness by exploiting the environment for tactical advantage. Environmental data can also be sent to regional centers and ultimately to the U.S. Naval Oceanographic Office to augment historical data. The TTS concept is minimally intrusive to the tactical sensor system, and typically consists of software modifications. The tactical capability of the system is unchanged. Additionally, TTS does not to interfere with the primary mission, affect vulnerability or safety. The technical feasibility of extracting bathymetry and sediment characteristics from AQS-20 data was demonstrated by NRL with AQS-20 test data sets taken in June 1998, July 1999 and June 2001[3].

Single beam bathymetry can be extracted from the mission tape in altitude following mode without interfering with other mission objectives. Extraction of single beam bathymetry from the AQS-20 was demonstrated using test data from a flight conducted in June 1998 just south of Panama City, FL. Water depth was computed by adding the pressure depth of the vehicle below the surface to the altitude of the vehicle above the bottom. Position of the tow body at the time of measurement was used for the position of the computed water depth. The tow body position data were generated from the GPS position of the helicopter, attitude and depth information from the AQS-20, and a cable layback model for the tow body. The data were corrected for roll and pitch of the vehicle. However, since the flight height above the bottom is small (on the order of 10 meters) the roll and pitch effect on position and computed water depth was insignificant. The data met MIW requirements for accuracy when compared to National Ocean Survey (NOS) ground truth data. The results from the data analysis were reported in the 4th International Symposium on Technology and the Mine Problem[4]. Due to its short range, the altitude sensor only works when the AQS-20 is relatively close to the seafloor, i.e. in the altitude following mode.

When the AQS-20 is in a depth following mode, nadir beam data from the VSS can be used to extract single beam bathymetry that meets MIW accuracy requirements. Due to the 1.4-yard range resolution of the *mission tape data*, the MIW requirement is met provided that the water depth is greater than 65 meters. In the mission tape, only a 2-bit intensity is recorded for display on a tactical screen. These intensity values are recorded at a range resolution of 1.4 yards. In the data analysis, the first high intensity amplitude signal from the nadir beam is interpreted as the seafloor and used to determine the altitude of the AQS-20 above the bottom. Single beam soundings are achieved by combining the altitude measurement with the pressure depth of the towbody and applying position information. This was demonstrated with VSS test flight data from a flight conducted in July 1999[5].

AQS-20 VSS *mission data* can also be used to extract limited multi-beam bathymetry that meets MIW accuracy requirements for water depths greater than 65 meters. This was demonstrated for the 5 VSS inner beams with data from the July 1999 test flight[5]. The VSS beam pattern, shown in Figure 3, is designed to detect mines in the water volume; however, it also detects the seafloor. Knowing the beam pair number and its relative angle from nadir, the depth of the bottom return along with its horizontal

offset can be calculated relative to the tow body. The mission tape also contains tow body depth below the surface and geographic position. Combining this information with the multi-beam data, the depth and position of each sounding can be calculated.

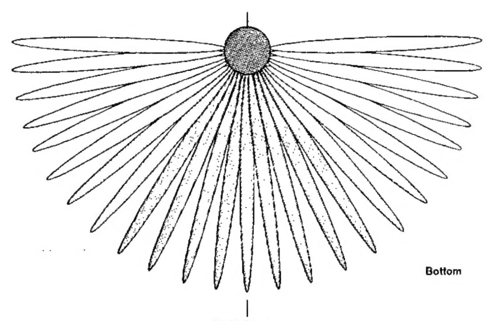


Figure 3
AQS-20 Towbody with Illustration of VSS Beams.

Better multibeam data can be extracted from the *high resolution* data stream. The *high resolution* data from the VSS has an advantage over the *mission* tape data because it is recorded with a 16-bit beam intensity time series at a much higher sample rate. This facilitates a more accurate peak detection used to determine beam range to the seafloor. Plus the resulting range resolution of 0.1yards allows more accurate depth and position resolution. The 16-bit data results in a wider swath of acceptable data and improved bottom detection.

A high-speed recorder is required to log the *high resolution* data. A prototype recorder was demonstrated in a dedicated AQS-20 environmental test flight on 14 June 2001 in the Gulf of Mexico just south of Panama City.

The VSS has 27 beam pairs forming a forward swath and aft swath of data that slightly overlap. Individual beam range to the seafloor is calculated using standard amplitude detection algorithms. This bottom detection technique is fairly reliable up to 45° from nadir thus providing an effective 90° swath[6]. This 90° swath contains 13 beam pairs yielding a maximum of 26 soundings total per ping. The actual number of acceptable soundings could be more or less depending on seafloor and water column conditions.

The tracks from the June 2001 test ran perpendicular to the depth contours to provide dramatic variation in bathymetry for evaluation against existing NOS data. Data from this test contained the raw beamformed acoustic time series for each beam of the VSS plus all of the towbody attitude and position information. Data processing of the raw beamformed data consist of several steps. The acoustic time series is deconvolved with the original source pulse to enhance the bottom return. The envelope magnitude is computed for the deconvolved data and used to identify the primary bottom return. A bottom detection algorithm is applied to the data and results in a two-way travel time of the acoustic pulse. Corrections for the sound velocity profile, towbody attitude and position are applied to the data to determine the corrected sounding location for each

beam. The data are then converted to Generic Sensor Format (GSF) and input into standard NAVOCEANO, commercial and open source multibeam processing and visualization packages.

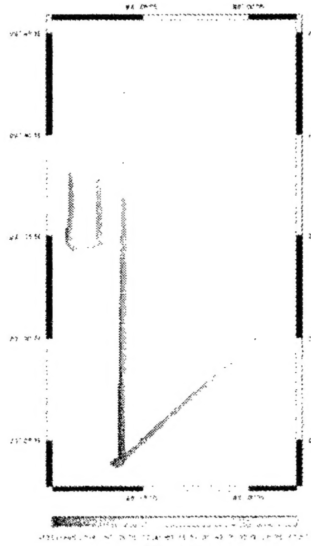
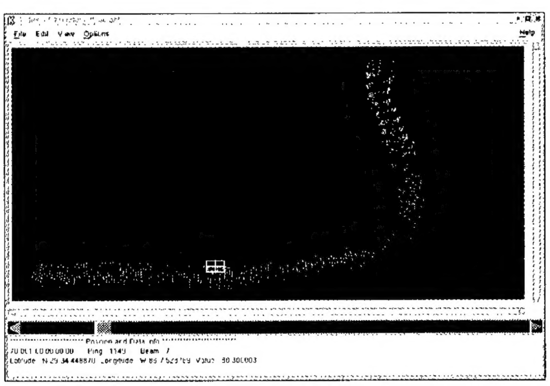


Figure 4
50 Miles of VSS Bathymetry
South of Panama City, FL, 14 June 01
MB Tools Visualization Software

Figure 4 shows the overall bathymetry from the 50-mile long flight path using MB Tools, open source display software. Depth varies from around 50 meters in the orange areas to 110 meters in the darker blue areas. Figure 5, left image, shows a closer zoom of the test data using NAVOCEANO's Bathymetric Hydrographic Processing Package (BHPP) routines. Figure 5, right image, shows a 3D view of the data near a ridge using University of New Brunswick's and Interactive Visualization Systems Fledermaus software.



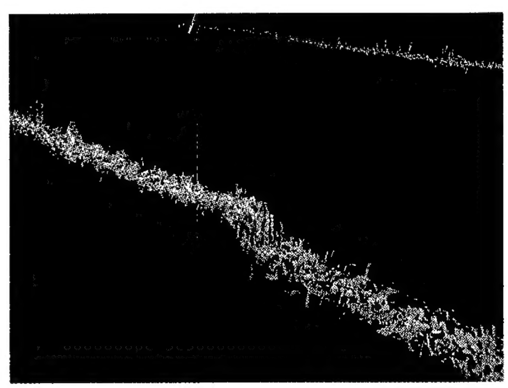


Figure 5
VSS Bathymetry
Left: NAVOCEANO's BHPP Software GeoSwath Tool
Right: Fledermaus Visualization Software

Existing NOS hydrographic data were used as 'ground truth' to compare with the AQS-20 bathymetry. NOS data points along the track were compared with VSS multibeam bathymetry and plotted in Figure 6. The mean difference between the VSS derived bathymetry and the NOS hydrography is 0.471 meters along the track segment shown. These results indicate that the VSS multibeam bathymetry meets the MIW requirements for water depth.

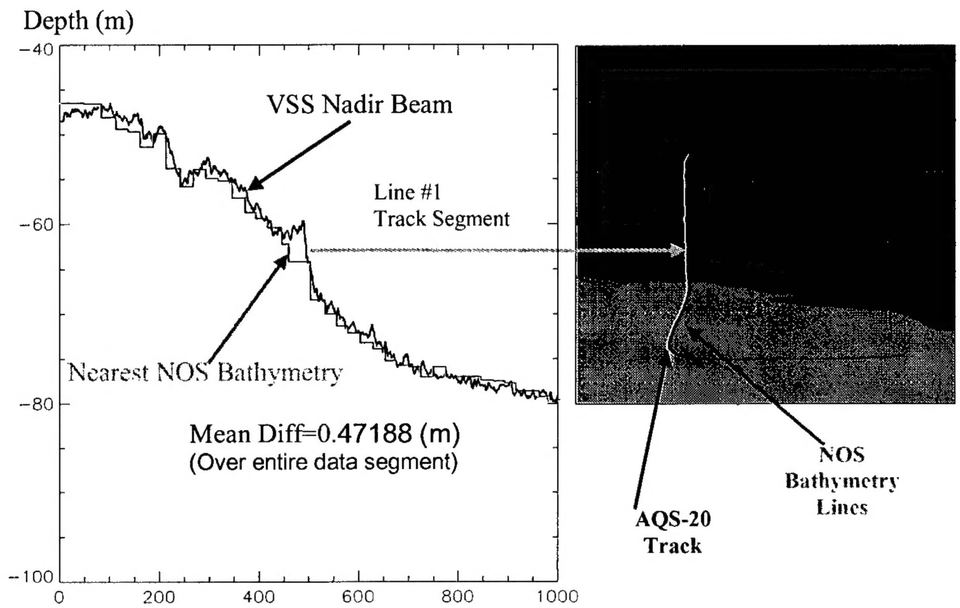


Figure 6
VSS Bathymetry Compared With NOS Bathymetry

VSS nadir beam data logged on the high speed recorder can also be used to determine bottom type sediment. Note this data can only be extracted from the 16-bit raw beamformed data. Full resolution data is needed to reconstruct the acoustic impedance and attenuation properties that characterize particular types of bottom materials. The mission tape data alone is insufficient to reconstruct a bottom type product, high-resolution data is required.

Extraction of bottom type information from the VSS was demonstrated using data from the 14 June 2001 AQS-20 environmental test flight. VSS time-varying receiver gain was set to a minimum value during the test. The bottom type characterization used only the two nadir (downward looking) beams from the VSS. Basebanded complex pressure data from this beam was extracted from the high speed recorder, frequency-shifted back to the original time series and deconvolved with the source pulse. The data were then put into the Acoustic Sediment Classification System (ASCS)[7, 8 and 9] which extracted the acoustic impedance and attenuation characteristics for the bottom and shallow sub-bottom. The ASCS system relates these bottom / sub-bottom properties to a bottom type (mud, sand, rock) and mine burial potential. These properties are combined with the VSS sonar ping location and plotted on a Seismic Display in the left image of Figure 7 and on a sediment classification display In the right image of Figure 7.

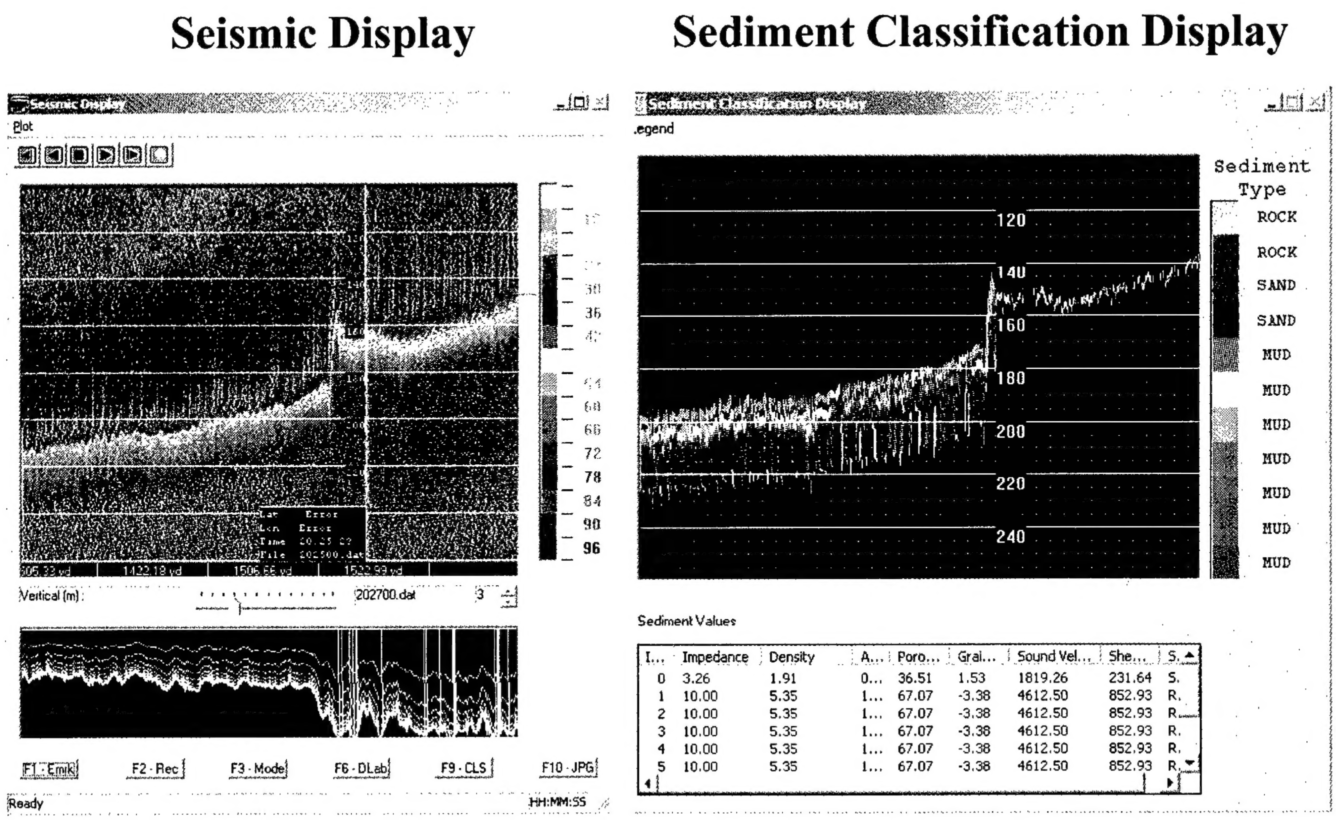


Figure 7
VSS Sediment Data, Panama City, FL, 14 June 2001
Seismic and Sediment Classification Displays, ASCS Software

To validate the VSS results ASCS bottom types were compared with grab samples collected along the tow track. The left side of Figure 8 shows VSS acoustic impedance values along the surveyed track. The right side of Figure 8 shows the sediment type, mud or sand, with grab sample locations and percentages of sand/mud for each sample taken. The grab samples agree with the ASCS processed VSS data. Additionally grab samples show sand at the top of the ridge shown on the right side of Figure 7, and mud at the bottom, which agrees with the ASCS sediment classification display. It is interesting to note the large variation in bottom type along the track. These changes in bottom type are correctly mapped by the VSS – ASCS system and represent a significant difference in mine burial potential.

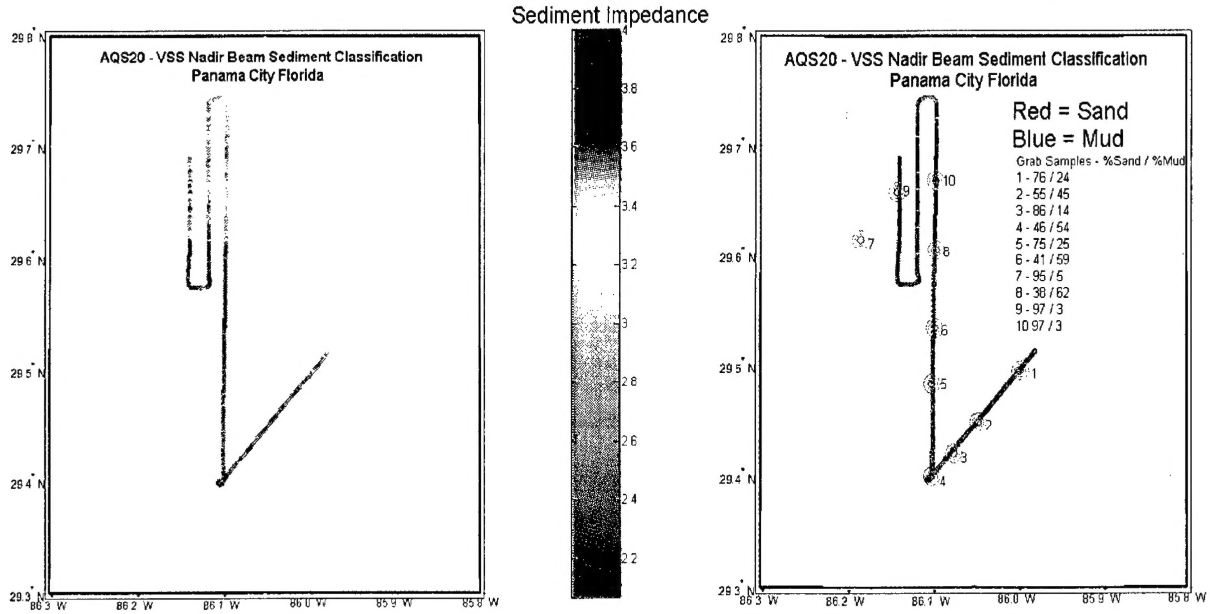


Figure 8
VSS Sediment Data, Panama City, FL, 14 June 2001
Left: Sediment Acoustic Impedance Along Track
Right: Sediment Type Compared to Grab Samples

It is interesting to note that the impedance plot indicates more information about the bottom type is available than a simple mud/sand distinction. The material classified as sand on the N-S lines at the top of the plots has higher impedance values than the sand on the NE-SW track in the lower part of the track. The grab samples agree with this assessment in that the higher impedances correlate with 97% sand (actually shelly-sands), while the lower impedance are a mixture of sands and muds (but still predominantly sand). Historical data from NAVOCEANO map both of these areas as gravelly sand. These distinctions are likely to become even more important to MEDAL as the acoustic propagation algorithm in that system migrates to Comprehensive Acoustic Simulation System-Gaussian Ray Bundle (CASS-GRAB).

Other environmental data types are in the AQS-20 data stream but are not the focus of this paper. The operational requirements documents were written broad enough to include other data types like CTD data, optical data, current data, and sidescan data. NAVOCEANO has already demonstrated the ability to use the side look sonar from the AQS-20 data to obtain sidescan type images and is planning to use this data like they are currently using sidescan data from the older AQS-14 sonar system.

EDC Mode

In the newly proposed EDC mode the AQS-20, flying at a constant depth, can interleave SLS and VSS pings using the single beamformer on the tow body. The EDC mode is the only mode that provides for collection of side-scan imagery, multibeam

bathymetry and sediment profile data during the same flight. Subsets of the listed environmental data can be collected on the other operational modes.

Operational requirements for the AN/WLD-1(V) state that data from the tactical sensors will also be recorded to extract physical environmental information as a Pre-Planned Product Improvement. This data will be extracted and processed post mission by a few specially trained sailors, referred to as a Mobile Environmental Team (MET), to evaluate MCM sensor performance, conduct sonar performance predictions, and perform mine burial estimates. Post collection data will be archived off board at NAVOCEANO to enhance MCM environmental databases.

Operationally the AQS-20 will be towed in a reconnaissance mode by the AN/WLD-1(V) Remote Minehunting System miles ahead of the battle group, and in an area search mode by the MH-60 helicopter.[10] Under the TTS concept the AN/WLD-1(V) would record high resolution environmental data from the Volume Search Sonar in addition to the normal mission data; however, only selected portions of the high resolution data would be recorded due to the long mission of the RMS and limited recording capacity. The MH-60 will conduct mine countermeasures from air-capable U.S. Navy ships. A portable high-speed recorder on the MH-60 would record all high resolution environmental data for individual flights. Normal mission data would also be recorded.

In Dedicated MCM operations environmental information from the mission tape and high resolution data tape would be taken from the AN/WLD-1(V) and/or MH-60 and processed by a MET Team, using NAVOCEANO's Bottom Mapping System. Processed data would be inserted into the Mine Warfare Environmental Decisions Aid Library for MCM evaluation.

Organic processing of environmental data is an issue. A standard configuration managed fleet system (processing computer and software) is needed. One proposal is to provide a Mobil Met Team in a concept similar to that used for Dedicated MCM Operations. The Bottom Mapping System, used in Dedicated operations, could be simplified and hardened to operate in an organic mode.

Conclusions & Future Recommendations

The technical feasibility of using the AQS-20 to extract environmental data in a TTS scenario has been demonstrated. The requirements exist and are in place to extract environmental data from the new AQS-20 mine hunting sensor. The one exception is the AQS-20X ORD, which is under review and has strong support from N752.

Based on AQS-20 test data it is technically feasible to extract multibeam bathymetry and sediment type information from the high-resolution data stream that meets accuracies required for mine warfare.

One outstanding issue that needs to be addressed is Organic processing of AQS-20 environmental data. No formal project has been established to develop organic processing software. The authors recommend first merging the processing capabilities developed under the SPAWAR PMW-155 TTS program into NAVOCEANO's Bottom Mapping System, used in Dedicated MCM exercises, as a Phase I effort. This should be followed by a Phase II effort to simplify and harden the processing so MET Teams can use the processing software in Organic operations

Future research efforts should be pursued to extract swath sediment type information from the VSS sensor data. Copies of the VSS data gathered from the 14 June 2001 AQS-20 environmental test flight have been provided to investigators working on NRL's 6.2 Through The Sensor Program and ONR's Generation and Exploitation of the Common Environment Program. After initial research a parallel effort in 6.4 is recommended to accelerate transition of the capability to an operational scenario. Extraction of environmental optical data should also be examined.

Acknowledgements

This work was sponsored under Program Element 0603704N by the Oceanographer of the Navy via SPAWAR PMW 155, Captain Bob Clark Program Manager. The authors would also like to acknowledge Captain L.F. Morris, Program Manager, Airborne Mine Countermeasures Program Office, and Captain Terry Briggs, Surface Mine Warfare Program Office for the cooperation and assistance received from their offices. Finally we would like to acknowledge the many dedicated engineers and scientists at the Coastal Systems Station, Naval Oceanographic Office, RAYTHEON and Lockheed Martin who have provided test support, requirements, and other information in support of extracting environmental data from the AQS-20.

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